Successes and Pending Tasks of Matlab Simulink

Successes of Matlab Simulink

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Abstract- **In this paper, the main advantages of Matlab Simulink were demonstrated on the basis of research works developed over the past few years. Simulink presents an open code that allows building researchers develop new tool boxes. These tool boxes give us the flexibility to improve building simulation considering the new parameters that are under investigation. Based on the open code and research works, more recent researchers could define, step by step, the effect of this heat and mass transfer over a building's energy consumption and thermal comfort. The International Energy Agency (IEA) organized efforts that were reflected in its different annexures. Consequently, pending tasks tend to utilize more user-friendly applications in respect of Comsol and Programmable Logic Controllers (PLC) applications, and new Heating Ventilation and air Conditioning (HVAC) control methods must be implemented so that, in the near future, a common working area for engineers and researchers is established.**

Keywords- Matlab; Simulink; Building Research

I. INTRODUCTION

Nowadays, engineers are frequently approaching researchers as their daily tasks tend towards sophistication, imagination, and multi-disciplinary knowledge. In this sense, a clear tendency in engineering studies towards a basic knowledge of the different disciplines in engineering was noted over the past couple of years. Thus, in these initial studies, applications like electrical, electronic, mechanical, thermodynamics, fluid mechanics, numerical methods, and programming languages are common knowledge for most engineers. From this common knowledge, graduate engineers find, in their real-world environment, new problems that were not envisaged in books and new teaching technologies. Furthermore, a new engineering task is to reduce processing cost, improve production, and expand the company's footprint in search of new markets. The engineer's originality often provides a typical solution.

Because of this real-life situation, most engineers need user-friendly and open-code software resources to adapt to each individual situation. For example, in previous years, marine engineers needed to adjust their maintenance tasks to suit each different power station. In this sense, different research works from departments of energy, mechanical, mathematics, and computers of the Universities of Coruña and Porto were developed to define better solutions for such problems. The results showed that a nearly forgotten tool called Visual Basic for Applications (VBA) allows the modification and adjustment of each different maintenance control parameter to suit an engineer's everyday routine work.

Over the past few years, similar advantages were detected in Matlab. Consequently, it has been employed by most professors to teach mathematics and, in most of cases, numerical methods, and to introduce programming languages. Furthermore, more specific subjects like Programmable Logic Controllers (PLCs) are trained with Matlab Simulink. The last is a Matlab tool box that presents a user-friendly way to understand mathematics and represent processes with block diagrams being one of the most important resources employed by engineers in their working life.

In this paper, the main advantages of Matlab Simulink reflected in research works developed over the past few years by different research units all over the world, will be summarized. In particular, Simulink presents an open code that lets building researches develop new tool boxes to improve building simulations considering new parameters that are being investigated [1-4]. For example, factors like heat and mass transfer through the building envelope were implemented and compared with private software resources. Step by step, and basing on these previous research works, recent researchers could develop more indepth investigations about the effect of this heat and mass transfer over a building's energy consumption and thermal comfort. The International Energy Agency (IEA [5]) organized efforts to improve these simulation processes in its different annexures like, for example, Annexures 41 and 55, to obtain more knowledge about building simulation. Once an in-depth knowledge about building simulation is reached, new standards for building certification and new software resources for general applications will be designed. This is the general procedure in actual research works about building simulation and indoor ambience.

II. MATERIALS AND METHODS

A. *Matlab Simulink*

Simulink is an environment for multi-domain simulation and model-based design for dynamic and embedded systems. It provides an interactive graphical environment and a customized set of block libraries that favor design, simulation, implementation and testing of a variety of time-varying systems, including communications, controls and signal, video, and image processing. Add-on products extend Simulink software to multiple modeling domains, as well as providing tools for design, implementation, verification, and validation tasks.

Simulink is integrated with MATLAB, providing immediate access to tools that allow development of algorithms, analyzing and visualizing simulations, creating batch-processing scripts, customizing the modeling environment, and defining signals, parameters, and test data.

B. *Ham Tools*

Ham tools is a new tool developed for Matlab Simulink by Angela Sasic [6-7] with the aim to simulate heat and mass transfer through the building envelope working under an open-code source. As it was commented upon previously, it gives engineers and researchers leverage to modify this whole-

building simulation code in accordance with conditions of each individual case.

HAM tools library is a Simulink model part of International Building Physics Toolbox, and is available for free downloading [8]. This library presents two main blocks: a building's envelope construction (walls, windows) and thermal zone (ventilated spaces). Component models provide detailed calculations of the hydro-thermal state of each sub-component in the structure according to the surrounding conditions to which each component is exposed.

In Fig. 1 we can see the principal blocks that represent the different exterior/interior walls, floor, roof, and window components defined, irrespective of their physical, thermal, and moisture properties, in accordance with the BESTEST structure. Building characteristics are defined in the thermal zone block showing the surface areas, orientations, and tilts of each wall. Room volume, solar gain to air, and initial temperature are adjusted accordingly. Other parameters like internal gains, air change, and heating/cooling systems are considered.

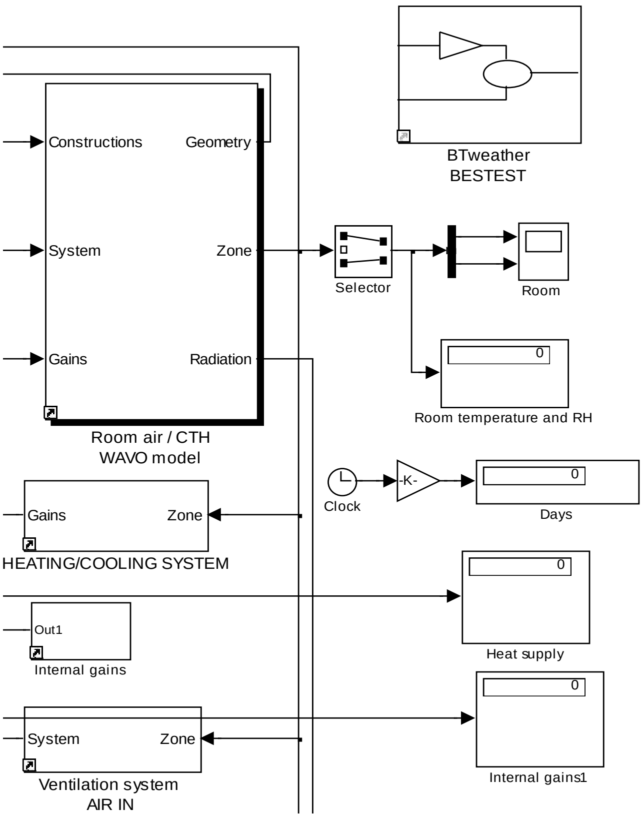

Fig. 1 Matlab blocks for building simulations

III. SUCCESS OF MATLAB SIMULINK

A. Simulation

In this paper, wall construction, indoor air renovation, and internal gains were adjusted in accordance with real buildings and simulated for some days of unoccupied period with the aim to define simulation accuracy in respect of real sample data. In this sense, a weather database was adjusted to actual weather conditions during these days basing on real outdoor air-sampling data.

Ham tools develops heat, air, and moisture balance that take into consideration moisture generated from occupants, moisture exchange by ventilation systems, and moisture transfer between indoor air and the building envelop. In this sense, heat transfer can be defined by conductive and convective processes, as it is reflected in (1)–(3).

$$q = q_{conductive} + q_{convective} \tag{1}$$

$$q_{conductive} = -\lambda \frac{\partial T}{\partial x} \tag{2}$$

$$q_{convective} = m_a \cdot c_{pa} \cdot T + h_{evap} \tag{3}$$

Where

λ is the thermal conductivity (W/mK)
T is the temperature (°C)
m_a is the density of moisture flow rate of dry air (kg/m^{2}s)
c_{pa} is the specific heat capacity of the dry air (J/kg K)
h_{evap} is the latent heat of evaporation (J/kg)

At the same time, during the calculation process, moisture flow transfer was separated in liquid and vapour phases, as we can see in (4) and (5).

$$m_l = K \cdot \frac{\partial P_{suc}}{\partial x} \tag{4}$$

m_l is the density of moisture flow rate of vapour phase (kg/m^{2}s)
K is the hydraulic conductivity
P_{suc} is the suction pressure (Pa)

The vapor phase was divided in diffusion and convection as we can see in (5).

$$m_v = -\delta_p \cdot \frac{\partial p}{\partial x} + m_a \cdot x_a \tag{5}$$

Where

δ_p is the moisture permeability (s)
x_a is the water vapour content (kg/kg)

The mass airflow through the structure driven by air pressure differences across the structure is shown in (6).

$$m_a = r_a \cdot \rho_a \tag{6}$$

Where

r_a is the density of the air flow rate (m^3/m^{2}s)
ρ_a is the density of the material (kg/m^3)

The final energy and moisture balance are shown in (7) and (8).

$$-\frac{\partial}{\partial x} q = c \cdot \rho_o \cdot \frac{\partial T}{\partial t} \tag{7}$$

$$-\frac{\delta}{\partial x} m = \frac{\partial w}{\partial t} \tag{8}$$

Where

ρ_o is the density of the dry material (kg/m^3)
c is the specific heat capacity of the material (J/kg K)
w is the moisture content mass by volume (kg/m^3)
t time (s)
x space coordinates (m)

The obtained discretized heat and moisture balance equations are shown in (9) and (10).

$$\frac{T_i^{n+1}-T_i^n}{\Delta t}=\frac{1}{C^n}\cdot\left\{\left[\frac{(T_{i-1}-T_i)}{R_{i-1}+R_i}+\frac{(T_{i+1}-T_i)}{R_{i+1}+R_i}\right]-h_{evap}\cdot\left[\frac{(p_{i-1}-p_i)}{R_{p,i-1}+R_{p,i}}+\frac{(p_{i+1}-p_i)}{R_{p,i+1}+R_{p,i}}\right]\right\}\cdots$$
$$+\begin{cases} m_a\cdot c_{pa}\cdot(T_{i-1}-T_i)^n, m_a>0 \\ m_a\cdot c_{pa}\cdot(T_1-T_{i+1})^n, m_a<0 \end{cases} \tag{9}$$

$$\frac{w_i^{n+1}-w_i^n}{\Delta t}=\frac{1}{d}\cdot\left\{\left[\frac{(p_{i-1}-p_i)}{R_{p,i-1}+R_{p,i}}+\frac{(p_{i+1}-p_i)}{R_{p,i+1}+R_{p,i}}\right]-\left[\frac{(P_{suc,i-1}-P_{isuc,i})}{R_{suc,i-1}+R_{suc,i}}+\frac{(P_{suc,i+1}-p_{suc,i})}{R_{suc,i+1}+R_{suc,i}}\right]\right\}\cdots$$
$$+\begin{cases} 6.21\cdot10^{-6}\cdot m_a\cdot(p_{i-1}-p_i)^n, m_a>0 \\ 6.21\cdot10^{-6}\cdot m_a\cdot(p_i-p_{i+1})^n, m_a<0 \end{cases} \tag{10}$$

Where i is the objective node and $i + 1$ and $i - 1$ are the preceding and following node, and n and $n + 1$ the previous and corresponding time steps.

To solve these balance equations, room models were created from the IBPT [9].

B. *Time Constant*

A building's thermal inertia is an intuitive term hard to be defined. For example, in an indirect way, it is described by the utilization factor. The utilization factor shows the part of energy gains that can be stored in the building construction, to be transmitted into the zone when needed. In this sense, it relates heat requirements with heat loss and heat gains, as we can see in (11).

$$Q_{heat} = Q_{loss} - \eta Q_{gain} \tag{11}$$

Where
Q_{heat} is the heat requirement (W)
Q_{loss} is the heat loss (W)
Q_{gain} is the heat gain (W)
η is the utilization factor, having a value between 0 and 1.

On the other hand, the utilization factor is a function of the time constant, as is shown in (12).

$$\tau = \frac{\sum C}{\sum H} \tag{12}$$

C is the sum of thermal capacity C of each construction based on a 24 h periodic response.
H is the sum of heat loss factor of each construction, ventilation and air leakage.

To define this time constant, real sampled data is usually employed. The time constant is normally found from a slow cooling-down period with a constant low outdoor temperature. It requires constant weather temperature, relative humidity, air velocity, rain, and global solar radiation conditions, among others, during as long as possible time periods.

Owing to the fact that it is very difficult to obtain this kind of constant weather condition during long periods of time, the real definition of a building's thermal inertia is not well defined and, therefore, research process is more difficult. As a possible solution to this problem, Ham tools offer a clear way to define these parameters. Two buildings with an expected high and low thermal inertia, in accordance with the thickness of each wall construction, were defined. Indeed, the old building presents the thickest wall and the new the slimmest. Once this software resource was adjusted to these particular conditions (Fig. 2), it was simulated under a constant climate.

From this simulation, the logarithm of the temperature difference indoors as compared to outdoors is taken and curve fitted to a straight line by the least squares method, as shown in Fig. 3. In this sense, we must remember that the time constant is the inverse of the coefficient for the independent variable (time) given by this curve fitting. In consequence, both buildings were simulated under constant weather conditions with the aim to determine building-time constants.

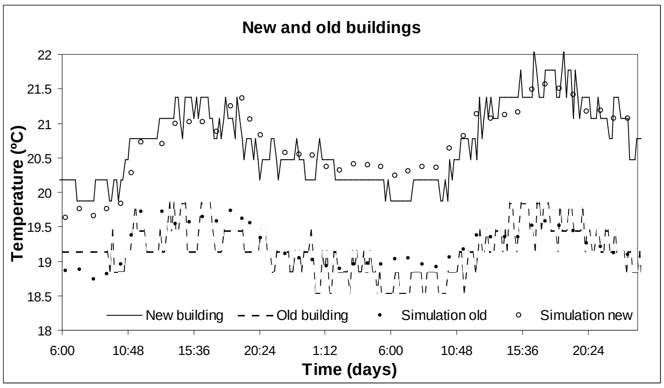

Fig. 2 Real sampled data and simulation results for new and old schools

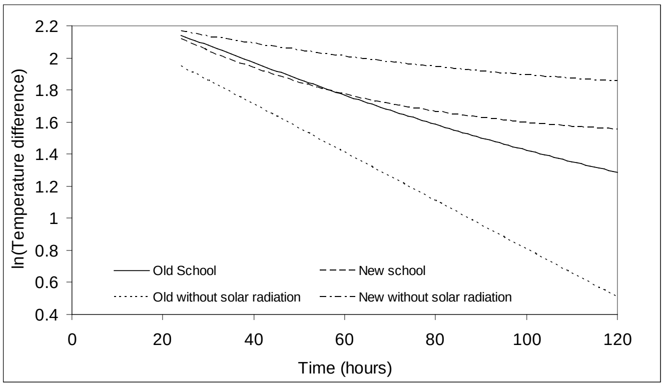

Fig. 3 Simulated data in old and new buildings with and without solar radiation effect

TABLE I TIME CONSTRAINT FOR EACH MODIFICATION

	Without Heat Gain	Initial Conditions	Air Renovation Reduction	Permeable Coverings
New	37	178	185	188
Old	67	111	112	115

Finally, different simulation alternatives like, for example, elimination of solar heat gains, reduction of the air changes, and implementing simulation with permeable coverings were proposed. All these results are shown in Table I. As we can see form this Table I, the new building shows a clear tendency to change its time constant when heat gains are eliminated and when air changes are reduced. On the other hand, the effect of permeable coverings was slight due to the fact that it was applied over a slow covering area.

C. *New Control Systems*

Another advantage shown by Simulink is that of simulating a real Heating Ventilation and Air Conditioning (HVAC) system under new control algorithms [10-11]. Furthermore, this HVAC system can be implemented in Ham tools since these results are still pending in-depth analyses. Furthermore, new HAVC systems must be developed in accordance with new control algorithms that are being defined by new researchers.

In this sense, new patents showed the feasibility of reducing a building's energy consumption with new HVAC control algorithms based on thermal comfort energy balances. Examples of this new control system methodology were simulated and validated with real sampled data over the past few years, and the main results will be shown in this section.

Nowadays, most engineers think that the real improvement in HVAC systems is related to a sensor's shorter time detection and a fast reaction to a heating or cooling system. Despite this, an adequate precision level in the control system was reached in recent years and today it is not the better approach to improve thermal comfort and energy consumption in buildings.

As it was shown earlier, a new control system based on new thermal comfort algorithms must be developed. In a simple way, previous works have defined thermal comfort with fixed set point temperatures from 18 to 23 ºC and from 23 to 27 ºC in winter and summer seasons, respectively, in accordance with standards [12-13]. These constant set point temperatures resulted in high energy consumption despite more adequate setting point temperatures and local thermal comfort not being considered at all.

During the research on thermal comfort, new local thermal comfort models were developed by researchers in previous years. Its results showed an adequate relationship between energy and thermal comfort by moist air enthalpy which can help us define the expected thermal comfort parameters. For example, when a thermal comfort algorithm is employed and fixed in each moment, the better the set point temperature, the clearer the increment in thermal comfort and decrement of energy consumption obtained. For example, in Figs. 4, 5, and 6, we can see real sampled temperature, relative humidity, and thermal comfort in an indoor environment.

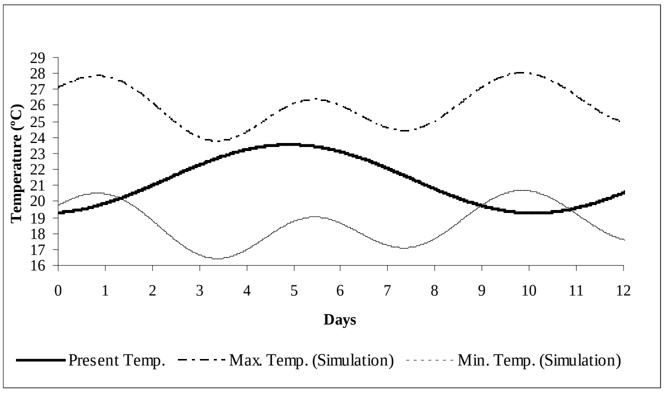

Fig. 4 Indoor ambience: sampled and simulated temperature

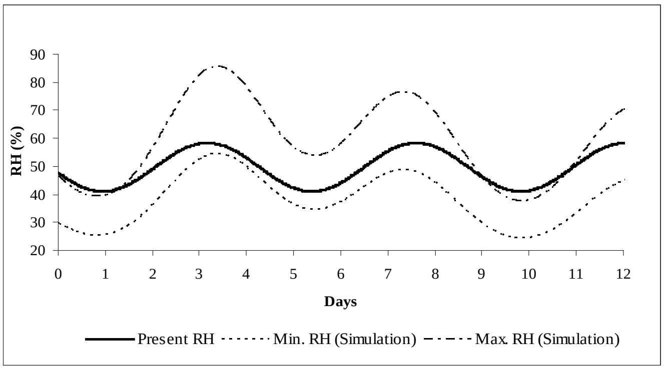

Fig. 5 Indoor ambience: sampled and simulated relative humidity

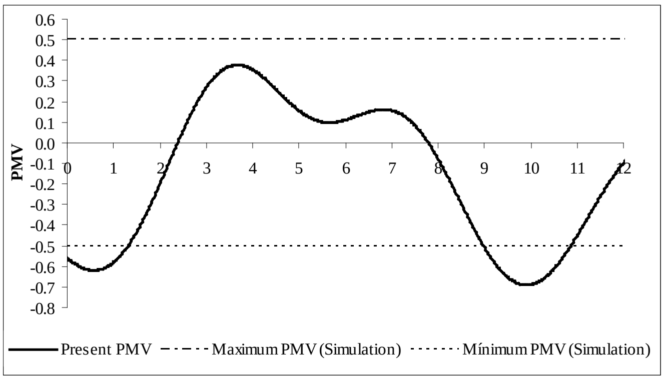

Fig. 6 Indoor ambience: sampled and simulated thermal comfort conditions

At the same time, these figures show that the maximum and minimum set point temperature in accordance with a maximum and minimum Predicted Mean Vote (PMV) algorithm. In consequence, the same indoor ambience will experience a change in its indoor relative humidity values.

Finally, from these results, we can conclude that each PMV value of +0.5 and –0.5 correspond to the lower energy consumption being within thermal comfort conditions in summer and winter seasons. This is a promising result that must be analyzed in future research works.

IV. FUTURE WORKS AND PENDING TASKS

Although Simulink is a user-friendly tool based on open-code sources, it presents some areas of improvement. Between them, we can find a need to improve Ham tools with a more in-depth knowledge about energy consumption and its related factors. Future improvements in Simulink are needed like, for example, a common need to define the effect of weather conditions over a building's energy consumption.

As it was shown earlier, thermal comfort can be a key parameter at the time of defining energy consumption. It is, when we try to define a building's energy consumption, one of the more important factors in thermal comfort. This parameter allows us to define the maximum and minimum temperature levels than can be found in an indoor ambience. In consequence, it defines to set point temperatures and its related energy consumption.

Despite this, thermal comfort is a general concept that must be adjusted to each different thermal environment. In this sense, a new concept of local thermal comfort must be improved considerably by the HVAC system. To define this comfort condition, new indexes are being developed and must be investigated in the near future.

In this sense, analyzing weather conditions and humidex showed adequate results. On the other hand, defining indoor local thermal comfort conditions as a percentage of dis-satisfied persons in real buildings to define the effect of internal coverings over a building's energy consumption and thermal comfort showed adequate behavior with a low cost in sensors. Thus, in developing this task only with sensors for temperature and relative humidity it was found that the results were very satisfactory.

Despite these efforts, it is a difficult state to achieve due to the fact that local thermal comfort is a subjective concept that is not easy to be defined. In consequence, only a percentage of the expected occupants who will be within the thermal comfort

conditions can be defined. In the near future, neuronal networks are the better approach and it will be advantageous to define indoor thermal comfort as a function of this kind of control system with ham tools. Usually, new standards are trusted in respect of real sampled data like, for example, the ISO 13790 Standard, among others. In this sense, a Ham tools simulation of actual standards over the sampled data can result in improving future standards and defining new validation tools like this useful software resource.

As was commented earlier, in each engineering academic study, we can find real case studies that must be solved by different private software resources. It will be beneficial to remember that all of them can be calculated by Matlab in different tool boxes, like Simulink, being a common working area for researchers and engineers. It could be an initial approach towards a more applied research work that, once started by engineers, it can be developed in depth by researchers speaking a common mathematical language and procedure. When we employ Matlab we can develop different algorithms by programming in C.

Despite this, it is not so simple a programming language like the forgotten VBA that presents a clear jump towards a visual and user-friendly programming method. For example, Simulink is a visual programming method that must be improved to be more easily adaptable to develop particular functions with software resources like Comsol and LabView.

Finally, using this software is only a beginning, but it will show amazing results in the near future if a common development platform between engineers and researchers is achieved.

V. CONCLUSIONS

In this paper, the main advantages of Matlab Simulink were shown based on research works developed in recent years by different research units. In particular, the Simulink open code allows building researchers to define new tool boxes like Ham tools that consider new parameters in an open way to be investigated in future works. In this sense, factors like heat and mass transfer through the building envelope could be defined with the help of private software resources. Furthermore, based on this open code, more recent researchers could define, step by step, the effect of this heat and mass transfer over a building's energy consumption and thermal comfort.

All these efforts were organized by the IEA in its different annexures like, for example, Annexures 41 and 55. The aim of these annexures is to obtain different points of view of a common problem from researchers and engineers in countries all over the world. More meetings are needed, and tasks must be developed over the next few years to solve the basis of building simulations and to develop new applications.

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